PROBING THE DEPTHS OF A SOLUTION FOR ACID MINE DRAINAGE

Acid mine drainage (AMD), caused by the physical and chemical weathering of sulfide-containing minerals such as iron pyrite, has been called one of the biggest threats to the environment in the United States. It is not confined to the United States, however; it is a global issue, affecting not only any country where mining activities have taken place but also neighboring countries, whose environments may be adversely affected by migrating pollution. According to the U.S. Environmental Protection Agency, AMD has polluted ground and surface water, and has rendered streams and even whole river systems unfit for human consumption and unable to sustain any form of wildlife. Efforts to treat the problem and control its spread cost the United States alone billions of dollars annually.

To fight AMD, scientists around the world must monitor and take samples from sites where it may potentially occur to check for oxidation, the first step in the process that results in acid drainage. Ideally, scientists would like to be able to sample *in situ*. Now, thanks to a new probe developed by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), that goal may be within reach.

AMD: Soil and Trouble

When minerals are ground up during the process of extracting ore, the grain size of the mineral is reduced, and the surface area available for weathering increases. In the eastern United States, the mining of high-sulfur bituminous coal is a prime source of AMD, while in the West the hard rock mining of copper, gold, silver, lead, zinc, and associated sulfide minerals contributes a great deal. Acidic debris can also come from road cuts and blasting through rock strata for highways.

Rainfall or stream runoff combines with oxygen from the atmosphere and sulfide from exposed minerals to create sulfuric acid. Acidic hydrogen ions are released into the waters that run from the mine tunnels and piles of excavated matter. Hydrogen-producing iron(III) ions are formed through the oxidation of iron(II), a process that is accelerated at low pH by the sulfide-oxidizing bacterium *Thiobacillus ferrooxidans.* Then the iron(III) ions hydrolyze in water to form iron(III) hydroxide, which releases still more hydrogen ions into the water and continues to lower the pH unless sufficient acid-neutralizing minerals are present in the rock to buffer any generated acid. The iron(III) hydroxide precipitates out of the water as a yellowish-orange slime that coats river beds and kills off virtually all bottom-dwelling aquatic life.

Not only can sulfides of heavy metals including cadmium, lead, and arsenic undergo the same process, this acidic solution can also leach heavy metals out of the ground, delivering them into waterways.

Lisa Kirk, a senior geochemist with Maxim Technologies of Bozeman, Montana, and a past chair of the Northwest Mining Association's Environmental Issues Committee, points out that when oxidation occurs, it doesn't automatically follow that acid is generated. "That depends greatly on the availability of neutralizing material such as limestone within the waste," she says. "The characteristics of the site have to be taken into account in all regards."

Still, when AMD does occur, it can have very undesireable effects. Results can include contaminated drinking water, disrupted growth and reproduction of aquatic plants and animals, a decline in valuable recreational fish species such as trout, and negative impacts on outdoor recreation and tourism.

AMD in the United States has polluted about 75% of a total 180,000 acres of reservoirs and 12,000-plus miles of streams and rivers, according to the Environmental Mining Council of British Columbia, a Victoria-based environmental reform group. The estimated cleanup cost is some \$32–72 billion, according to *Burden of Gilt*, a 1993 publication by the Mineral Policy Center, a Washington, D.C., nonprofit organization.

The council estimates in its online report *Acid Mine Drainage: Mining & Water Pollution Issues in BC* that in Canada as of 1998 mining operations had yielded 351 million metric tons of waste rock, 510 million metric tons of sulfide-containing tailings (ground-up mined rock), and more than 55 million metric tons of other potential mining sources of AMD such as displaced surface matter. The council further states that cleanup at the more concentrated acid-generating mines in Canada will cost some Can\$2–\$5 billion, and in British Columbia alone, the stockpile of acidic and heavy metal–contaminated tailings and waste rock from mining is growing by 25 million metric tons each year.

One common method for preventing the formation of AMD is by keeping acidic waste rock deposits either continually submerged in water and isolated from air or as dry as possible, buried under a barrier such as clay, to eliminate one or the other of the reaction components. But as with any system where nature and humans interact, there is no perfect barrier. Leakage takes place, and the key is to be able to detect that leakage and any sulfide oxidation that results, and to deal with it before it contaminates the environment.

To date, the only way to check for such infiltration of air and/or water is through taking an actual physical sample of subsurface gas. Brought back to the surface, a gaseous sample is run through a gas chromatograph, which can detect the presence and level of oxygen. If oxygen is found in the sample, it very likely indicates that the containment system is allowing air into the waste.

But it's possible to accidentally contaminate a sample with oxygen once it is brought to the surface. This is where the need for an *in situ* sampling method comes in.

A drain on the environment. Acid mine drainage of heavy metals including cadmium, lead, and arsenic threatens waterways with toxic contamination.

Joe Zambelli/West Virginia Department of Environmental Protection

Down and Dirty Means Cleaner Samples

Bradley Patterson, an environmental chemist with CSIRO Land and Water, is part of a team that has developed a small electrochemical probe that can be buried in a mine waste site. The probe sends a signal up a thin wire to the surface, where a recording station receives the signal for analysis, either on location or via cell phone connection for remote locations.

"Our group has been active in research regarding remediation of contaminated sites," says Patterson, "especially those contaminated by organics like gasoline. For microbial cleanup of an organic compound like that, you need the presence of oxygen, so we originally developed this probe to determine the amount of oxygen being delivered to subsurface sites. It wasn't a great leap from that point to use the probe to detect oxygen in sealed mine waste sites."

According to Patterson, the main benefit of this technology is that it allows *in situ* monitoring, thus avoiding the risk of sample contamination. "With this probe," he says, "you don't have to collect a physical sample and bring it to the surface. [The probes are] designed to be lower in cost, they last for years, and they yield data that's relatively easy to interpret."

Patterson says the probes are made of ridged polyvinyl chloride, an inert substance resistant to the acidic environment that occurs in these sites, and they can detect oxygen in air and water at concentrations as low as 0.2%. Approximately 20 cm long and 4 cm in diameter, the 200 g probes are typically buried 50–100 m apart in drier soils, more closely in water-saturated soils.

According to Patterson, the probes are designed to be used in conjunction with the types of covers industry typically uses for these wastes. "You prevent the formation of an acidic solution by preventing the ingress of oxygen, and the probe will tell you if you're doing a good job or not," he says. "If it picks up oxygen, you know you've got a problem, because as the pyrite oxidation in the AMD process consumes oxygen, if oxygen was present this would indicate possible significant oxygen ingress compared to oxygen consumption, and you can address it before the situation gets out of control."

The probe's design relies on diffusion through a slotted screen into a chamber housing a semipermeable membrane, and diffusion through that membrane into a 1.2 mL–volume space that houses an electrochemical sensor. The oxygen sensor consists of a lead oxygen cell with a lead anode and gold cathode. Oxygen entering the sensor is converted to water at the gold electrode, producing a current flow that is proportional to the oxygen concentration. That current is measured as a voltage and converted to an oxygen concentration, using exposure to the atmosphere prior to installation as a reference.

In the late 1990s, CSIRO ran an experiment where several probes were buried within a sulfide-rich tailings repository, in both clean sand above and tailings below a synthetic liner that had been installed to prevent oxygen from reaching the mineral and triggering the formation of sulfuric acid. Measurement of oxygen above and below the liner allowed researchers to compare oxygen ingress from the atmosphere with oxygen usage at the particular depths of the probes.

Monitoring for six months, the team discovered that while oxygen concentrations in the clean sand were near atmospheric levels, there were considerable fluctuations in readings below the synthetic liner over time, which indicated the liner was poorly sealed. Water was pumped in to further seal the bentonite clay used to secure the synthetic layer, and further monitoring showed a cessation of the fluctuations and a decrease in oxygen concentration to less than 0.5%, suggesting the leak had been sealed (normal atmospheric oxygen concentration is about 21%, by contrast).

Toward a Rock-Solid Technology

Exceptionally robust, the probes are designed to last from two to five years (some test site probes have been buried that long and are still functioning), but Patterson admits the wires are a potential weak link in the system. "There is certainly the potential for damage, especially in an industrial or mining situation," he says. "When you're dealing with larger earth-moving equipment, the probes would have to be well-buried and clearly marked."

Has the CSIRO team considered the possibility of using a wireless data transmission method? "That's not something we've looked at," Patterson admits, "although it is certainly possible. The problem with that would be twofold—it would require greater power than we have available in the probe, and it would raise the cost substantially by having to build in more technology. This is designed as a lower-cost solution to the problem."

Power probe. A new mine probe can detect oxygen, a key ingredient in the formation of acid mine waste, enabling early prevention measures.

Bill van Aken/CSIRO Land and Water

Patterson says he and his colleagues are currently in negotiations regarding commercialization of the product, and declines to speculate on exact costs of the probe and monitoring equipment.

To date, the probes have been installed only in sandy or clay environments, not rock dumps. "I would assume that in a rock dump [which shifts over time], you may need to install the probes in some sort of bedding sand to reduce the [risk] of crushing the probes, and encase the wires in some type of conduit," says Patterson.

"It would be an interesting development," says Lisa Sumi, research director of the Environmental Mining Council of British Columbia, "of course, only as long as you could be assured it was a reliable monitoring method. And the other problem is that this waste is typically such a heterogeneous mixture [meaning the onset time of acidification, the buffering capacity of the alkaline minerals, and other factors are notoriously hard to pin down]. I'd be concerned if this was the only method of monitoring the waste."

Says Kirk, "Oxygen measurement is one of several methods to track oxidation in sulfide-bearing mine waste, and I'd like to see a probe like this used in conjunction with temperature measurements [another good way to assess the rate of oxidation] and water quality, particularly pH and sulfates. Tailing material in particular is typically quite homogeneous, but only in terms of its size. As you move through layers of rock during mining operations, you naturally get variations in sulfide level and neutralization potential, so I think you need more than one method of monitoring to provide a complete picture.

"People tend to view acid drainage as inevitable, but I disagree," Kirk adds. "I think the advances that are coming out of institutions like CSIRO and other agencies, in both storage and monitoring, are tremendously promising."

Lance Frazer

Suggested Reading

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